UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS: None

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE:

3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): NORDA Report 129

5. MONITORING ORGANIZATION REPORT NUMBER(S): NORDA Report 129

6. NAME OF PERFORMING ORGANIZATION: Naval Ocean Research and Development Activity

7a. NAME OF MONITORING ORGANIZATION: Naval Ocean Research and Development Activity

6c. ADDRESS *(City, State, and ZIP Code)*: Ocean Sciences Directorate, NSTL, Mississippi 39529-5004

7b. ADDRESS *(City, State, and ZIP Code)*: Ocean Sciences Directorate, NSTL, Mississippi 39529-5004

8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Naval Ocean Research and Development Activity

8b. OFFICE SYMBOL *(If applicable)*:

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS *(City, State, and ZIP Code)*: Ocean Sciences Directorate, NSTL, Mississippi 39529-5004

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
63704N			

11. TITLE *(Include Security Classification)*: NORDA Participation in the SSM/I Sea Ice Validation Experiment

12. PERSONAL AUTHOR(S): Duane T. Eppler and Jeffrey D. Hawkins

13a. TYPE OF REPORT: Final

13b. TIME COVERED: From ______ To ______

14. DATE OF REPORT *(Yr., Mo., Day)*: September 1985

15. PAGE COUNT: 28

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS *(Continue on revere se if necessary and identify by block number)*: SSM/I, sea ice, remote sensing, Arctic

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The Special Sensor Microwave/Imager (SSM/I) will provide the Navy with a global capability to measure sea ice, wind speed, water vapor, rain rate, and several other atmospheric parameters. The sea ice retrievals will go a long way toward filling a present gap in analysis data sets. Thus, proper validation of this sensor's abilities is required if the full potential is to be achieved.

Naval Ocean Research and Development Activity (NORDA) personnel have access to a number of ground, aircraft, and spaceborne instruments that can contribute to SSM/I sea ice validation efforts. Ice camps, the K-band Radiometric Mapping System (KRMS), and satellite visible and infrared data can all provide a piece of the puzzle when addressing the issue of algorithm performance.

It is essential to include ground, air, and spaceborne resources to tackle the task of validating the sea ice information retrieved from SSM/I data. Not only must we cover large geographic regions synoptically, but we must also be able to discern smaller irregularities found within the SSM/I cell footprints. Only then can we push algorithms to their required limits.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ■ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL: Duane T. Eppler

22b. TELEPHONE NUMBER *(Include Area Code)*: (601) 688-4812

22c. OFFICE SYMBOL: Code 332

DD FORM 1473, 83 APR

EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

Naval Ocean Research and Development Activity
September 1985

NORDA - Report 129

NORDA Arctic Data Collection, Processing, and Interpretation Capabilities

Duane T. Eppler
Oceanography Division
Ocean Sciences Directorate

Jeffrey D. Hawkins
Ocean Sensing and Prediction Division
Ocean Sciences Directorate

Foreword

Since its inception, the Naval Ocean Research and Development Activity has actively pursued a number of research objectives in the polar regions. These efforts will enable us to join the verification program being formulated for the Special Sensor Microwave/Imager (SSM/I). The success of this effort is critical since the SSM/I can significantly contribute to the day-to-day polar operations the Navy must continually encounter.

R. P. Onorati, Captain, USN
Commanding Officer, NORDA

Executive summary

The Special Sensor Microwave/Imager (SSM/I) will provide the Navy with a global capability to measure sea ice, wind speed, water vapor, rain rate, and several other atmospheric parameters. The sea ice retrievals will go a long way toward filling a present gap in analysis data sets. Thus, proper validation of this sensor's abilities is required if the full potential is to be achieved.

Naval Ocean Research and Development Activity (NORDA) personnel have access to a number of ground, aircraft, and spaceborne instruments that can contribute to SSM/I sea ice validation efforts. Ice camps, the K-band Radiometric Mapping System (KRMS), and satellite visible and infrared data can all provide a piece of the puzzle when addressing the issue of algorithm performance.

It is essential to include ground, air, and spaceborne resources to tackle the task of validating the sea ice information retrieved from SSM/I data. Not only must we cover large geographic regions synoptically, but we must also be able to discern smaller irregularities found within the SSM/I cell footprints. Only then can we push algorithms to their required limits.

Acknowledgments

The data examples illustrated in this report represent the work of many individuals in the Polar Oceanography and Remote Sensing Branches. The experience and knowledge noted within were acquired during numerous field progams sponsored by a number of funding agencies. The compilation of this report was directly supported by CNO OP-006 (formerly OP-952) under program element 63704N, Satellite Oceanography Tactical Application Program, A. E. Pressman, Program Manager.

Contents

NORDA Arctic data collection, processing, and interpretation capabilities

I. Introduction

The Special Sensor Microwave/Imager (SSM/I), scheduled for launch aboard a Defense Meteorological Satellite Program (DMSP) spacecraft in 1986, will be the Navy's primary polar sensor for the next decade. The SSM/I will provide multispectral images of the polar regions and replace the aging Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR). SSM/I data will be used to detect and help forecast the extent, concentration, and age of sea ice throughout the Arctic and Antarctic. Thus, development of reliable techniques for treating data gathered by the SSM/I is critical to Navy sea ice analysis and forecasting efforts.

The SSM/I will provide passive microwave images of the earth's surface at four frequencies: 19.35 GHz, 22.235 GHz, 37.0 GHz, and 85.5 GHz. Vertical and horizontal polarizations are measured in all but the 22.235 GHz channel, where only vertically polarized radiation is sensed. The instrument is aft-viewing and scans a swath 102° wide (1394 km) centered on the satellite ground track. This swath width, when combined with the high inclination DMSP orbit, will enable imagery of all polar regions below 87.6°.

The look angle of the instrument is 53.1° from nadir and is constant for all pixels and frequencies. The individual footprints are oval, due to antenna characteristics and the high incidence angle, and range in size from 70x45 km for the 19 GHz channel to 16x14 km for the 85 GHz channel. Table 1 summarizes many important features of the SSM/I.

Multispectral data returned by the SSM/I will carry abundant information concerning ice conditions throughout polar regions. Of special interest is information regarding location of the ice edge and open water within the pack, total ice concentration, and first- and multiyear ice fractions. Analytic techniques developed to retrieve these parameters from SSM/I data are based mainly on algorithms that extract ice concentration data from SMMR images (Swift, et al., 1985; Cavalieri, et al., 1984; Svendsen, et al., 1983). The SSM/I instrument, though similar in design to the Nimbus and SEASAT SMMRs (Gloersen and Barath, 1977), provides data in an assemblage of frequencies not previously available on satellite platforms. As a result, direct correspondence between SMMR and SSM/I sea ice algorithms can not be assumed. Therefore, values derived with these algorithms must be validated.

Table 1. SSM/I instrument characteristics.

Frequency (GHz)	19.35	22.235	37.0	85.5
Wavelength (cm)	1.55	1.35	0.81	0.35
Polarization	V/H	V	V/H	V/H
Footprint (km)	70×45	60×40	38×30	16×14
Temperature Resolution (K)	0.66	0.66	0.46	1.01
Antenna Beamwidth	1.98°	1.72°	1.06°	0.45°
Integration Time (ms)	7.95	7.95	7.95	3.89

Any validation effort keyed to the SSM/I sensor must adequately take into account the cell resolution mandated by the instrument's altitude, frequencies, and incidence angle. Otherwise, a mismatch will lead to erroneous results. Moreover, the emissivities and brightness temperatures required to implement the algorithms fully, must ultimately come from SSM/I sensors after launch. In the end, accuracy and reliability of sea ice parameters based on SSM/I sea ice algorithms can be assured only when information retrieved from SSM/I data are verified via independent observations.

NORDA holds multidisciplinary assets that are well suited to provide these independent observations. The SSM/I validation experiment provides an appropriate scenario in which to demonstrate how these assets can be brought to bear on an applied problem. Accordingly, our objectives here are twofold: (1) to describe relevant NORDA assets held by the Remote Sensing and Polar Oceanography Branches, and (2) to describe their application to a specific problem of Navy interest, the SSM/I sea ice validation experiment. First we provide background information concerning sea ice algorithms that would be tested and fine tuned in the course of such an effort.

II. SSM/I sea ice algorithms

Candidate SSM/I algorithms fall into three categories: ice concentration algorithms, ice edge algorithms, and the

Hughes algorithm. Because the SSM/I validation experiment is intended to provide ground truth data in support of these algorithms, we provide a brief discussion of each algorithm category.

A. Ice concentration algorithms

In April 1984, NASA established the SSM/I Sea Ice Algorithm Working Group to evaluate the strengths and weaknesses of candidate SSM/I sea ice algorithms. The working group was to recommend one algorithm for implementation in NASA's Pilot Ocean Data System (PODS), the primary channel through which SSM/I data will be distributed to the scientific community. Three state-of-the-art algorithms were considered: the Swift/AES algorithm (Swift et al., 1985), the Norwegian algorithm (Svendsen et al., 1983), and the Nimbus Team algorithm (Cavalieri et al., 1984).

The effect of systematic errors (air temperature and surface temperature) and random errors (instrument noise) on retrievals of total ice concentration, first-year ice concentration, and multiyear ice concentration was examined. The Nimbus Team algorithm is substantially more robust with respect to systematic errors than either of the other two algorithms (Swift et al., 1985). Moreover, although the Nimbus Team algorithm is less robust with regard to random error than either the Swift/AES algorithm or the Norwegian algorithm, concentration retrievals from the Nimbus algorithm remain within acceptable error limits. Accordingly, the working group recommended that NASA implement the Nimbus Team algorithm in its PODS processing stream.

B. Ice edge algorithm

Svendsen et al., (1985) present an algorithm that uses information in the 85-GHz channel to map ice/water boundaries. The algorithm capitalizes on the improved spatial resolution offered by the 85 GHz channel (approximately 15 km per footprint, Table 1) to resolve location of ice edges more precisely than previously possible with satellite-borne passive microwave imagers. Because the SSM/I is the first satellite sensor to offer 85 GHz data, the algorithm is untested.

C. Hughes algorithm

The Hughes algorithm, developed by Environmental Research Technology (ERT) under contract to Hughes Aircraft (builder of the SSM/I), has been designated the primary Navy operational SSM/I algorithm. Accordingly, it is implemented on Navy computers at the Fleet Numerical Oceanography Center (FNOC) in Monterey, California. The Hughes algorithm derives ice concentration values using data from only the 19 and 37 GHz channels. Use of these channels at the exclusion of others places severe restrictions on the type and quality of information that can be extracted from SSM/I imagery.

Previous work clearly demonstrates that the accuracy of ice concentration retrievals improves significantly when other frequency channels are analyzed in conjunction with the 19 and 37 GHz channels (Cavalieri et al., 1984; Swift et al., 1985). Moreover, the fact that higher resolution data from the 85 GHz channel are ignored represents a critical oversight where smaller scale ice edge and polynya features are required.

III. NORDA assets

A. Airborne assets

1. Passive K-band microwave imager

NORDA's K-band Radiometric Mapping System (KRMS) is an airborne passive-microwave imager that operates at a center frequency of 33.6 GHz. The instrument was built and is maintained for NORDA by civilian personnel at the Naval Weapons Center, China Lake, California. Important characteristics of the instrument are given in Table 2. The instrument is pod mounted (Fig. 1) and, in its present configuration, is hung from the bomb bay of an RP-3A aircraft (Fig. 2). A modified door and rack that accompany the KRMS pod must be installed in the bomb bay when the pod is mounted. The modified door and rack fit RP-3A airframes.

Microwave radiation emanating from the earth's surface is detected by three parabolic antennas located near the front of the pod. The antennas, mounted 120° apart on a single shaft (Fig. 3), rotate about a horizontal axis parallel to the direction of flight, and provide between 7 and 25 scans of the ground per second. Rotation rate is controlled by the operator in the aircraft and can be varied to compensate for altitude and airspeed changes.

Use of three antennas permits continuous ground coverage at altitudes of 1000 ft and above. Although each antenna scans 120° centered at nadir, only 100° of the available 120° cross-track scan is used. Resultant cross-track coverage is equal to 2.38 times altitude, or approximately 2 NM at 5000 ft. Antenna beamwidth is 1° so that spatial resolution of the unprocessed signal is 16 ft per 1000 ft of flight altitude. Resolution of 12 ft per 1000 ft of altitude is achieved using conventional signal

Table 2. KRMS technical characteristics

ANTENNAS	
number	3
diameter	24 inches
polarization	vertical
beamwidth	1.0°
isolation	40 dB (minimum)
SCANNER	
maximum scan rate	25 scans/second (40 ms/scan)
minimum scan rate	7.5 scans/second (133 ms/scan)
scan angle	60° from nadir
midscan incidence angle	0° (nadir)
scan width	3.46 x altitude
antenna position accuracy	2.5 minutes of arc
STABILIZATION	
method	cross-track roll gyro
accuracy	less than 0.25°
RF AMPLIFIER	
type	Superheterodyne (DSB)
noise	less than 5.0 dB
bandwidth	1.3 GHz
gain	greater than 60 dB
loss	1.2 dB (maximum)
RADIOMETER	
type	pulse stabilized, total power
pulse width	4.0 MS
local oscillator frequency	33.6 GHZ
IF bandwidth	greater than 500 MHz
video bandwidth	1.7 kHz (maximum)
video gain	72 dB (nominal)
minimum detectable signal	0.05 K/second
sensitivity	50 mV/K (nominal)
dynamic range	370 K

processing techniques. Radiometric sensitivity measured in the laboratory is 0.05 K/sec. Operational sensitivity is 0.5 K, or better.

Microwave energy detected by the antenna assembly is converted to an RF signal and split into two channels. One channel is recorded on analog tape for subsequent laboratory processing. The other channel is fed to the onboard display processor (Fig. 4), where it is converted to digital format and displayed in real-time. Hard-copy paper prints (Fig. 5) are produced directly from the video signal and can be dropped to ground parties minutes after images are acquired. Image processing functions can be stored in the onboard display processor and allow standard enhancement techniques to be applied to the real-time image.

When the mission is completed, the analog tape is returned to the laboratory for processing and geometric and radiometric aberrations are corrected. Cross-track distortion that arises from beam spreading is corrected by applying a simple tangent function to compensate for the increased incidence angle. Signal variation, which arises from differences in the response characteristics of the three antennas, is removed. Earth location of image segments is derived by comparing the time code recorded on the analog tape with navigation logs. Finally, the signal is digitized and calibrated, and brightness temperatures are calculated according to procedures presented by Eppler, et al. (1984). Once calibration is complete, KRMS images are stored on magnetic tape or disk.

2. Aerial photographs

NORDA in-house capability consists of a Wild RC-10 aerial photographic mapping camera and a KS-87 aerial reconnaissance camera. The Wild RC-10 produces 9 inch square images (Fig. 6). Each roll holds approximately 400 images. The camera is equipped with a 6-inch lens that provides a 74° field of view. Resolution is approximately 0.262 ft per thousand feet of altitude; thus, images made at 5000 ft altitude resolve features as small as 1.3 ft. Images made at 20,000 ft resolve objects as small as 5.2 ft. The camera requires a 22-inch window in the aircraft belly.

The KS-87 provides images on 5-inch-wide roll film. Each roll holds approximately 800 exposures. Resolution is approximately half that obtained with the RC-10, assuming that a 3-inch lens of comparable quality is used to provide a similar field of view (74°). Resolution at 20,000 ft altitude is reduced to approximately 10.4 ft. Resolution comparable to that of the RC-10 can be obtained using a 6-inch lens, but the field of view is reduced by half to 37°. The KS-87 requires a 12-inch window in the aircraft belly.

3. Shared airborne assets

Use of some aircraft brings opportunities to use instruments owned by other agencies. For example, NAVOCEANO assets that accompany its P-3 research aircraft include a Spectra-Physics laser profilometer and a Barnes PRT-5 radiometer. The laser profilometer records surface roughness and the PRT-5 records surface physical temperature.

B. Ground-based assets

NORDA field capability provides support for small to medium-sized remote camps located on drifting sea ice (Fig. 7). Camps can accommodate up to 20 people for as long as four weeks at a time. Ten heated Hanson Weatherport shelters (five 12 x 20 ft shelters and five 12 x 10 ft shelters) are available to house personnel and equipment. In-house communications equipment provides contact with shore stations and airborne support platforms at most HF and VHF frequencies. Locator beacons placed at each

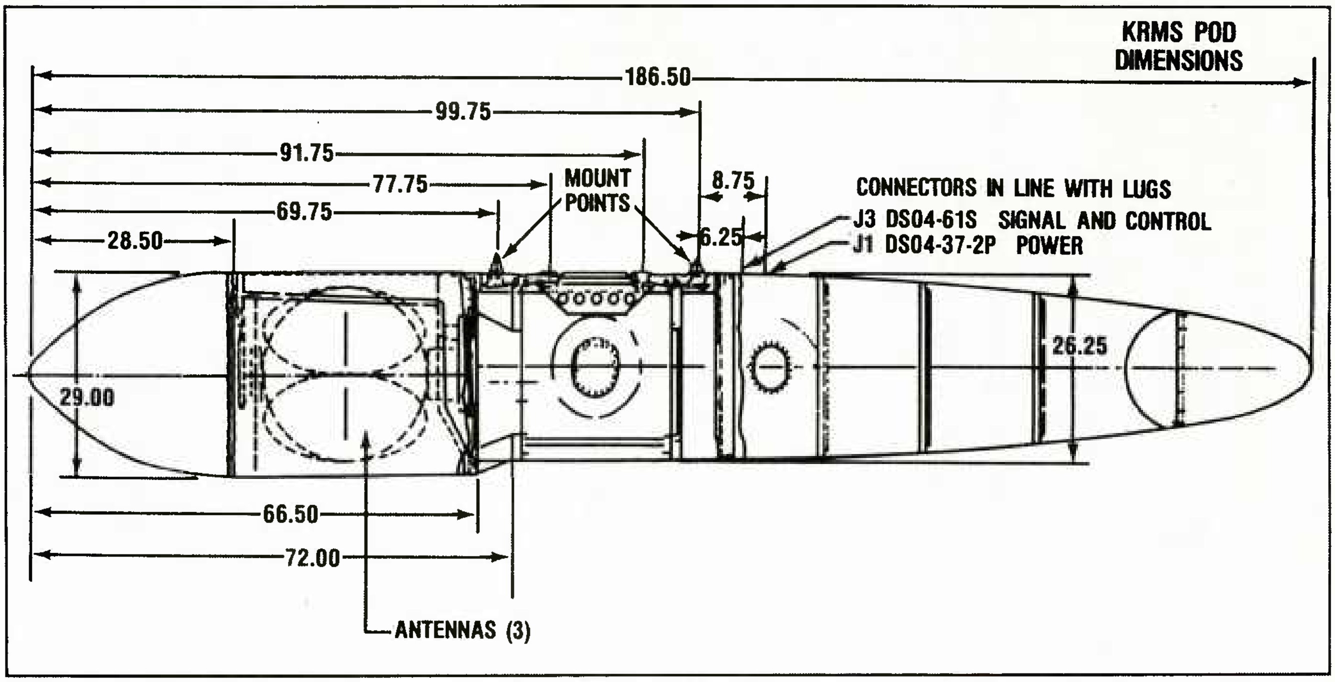

Figure 1. Side view of the KRMS pod. The rotating antenna assembly is located beneath the radome near the front of the pod. Note mount points and electrical connectors on top of the pod immediately aft of the antennas. Pod weight is approximately 500 pounds. Dimensions are in inches.

Figure 2. KRMS pod mounted in the bomb bay of the Naval Oceanographic Office RP-3A aircraft.

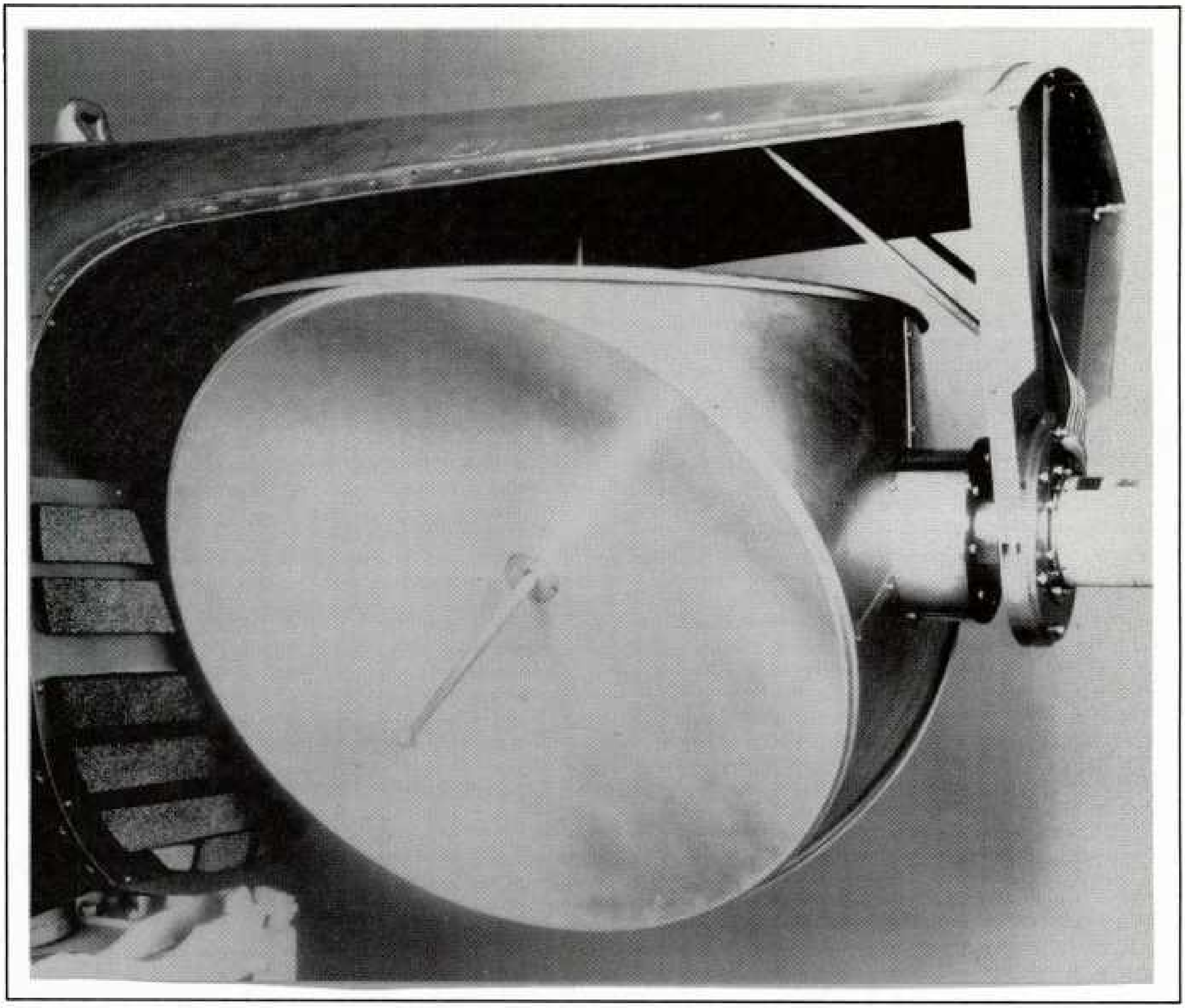

Figure 3. KRMS antenna assembly. The radome has been removed from the pod to show the three parabolic reflectors that comprise the antenna assembly.

field site aid aircraft in locating remote camps. NORDA personnel maintain these camps and direct set-up and break-down operations.

Scientific field equipment includes a suite of automated weather stations, instruments to measure snow and ice properties, and instruments to measure passive microwave properties of sea ice at 33.6 GHz. Weather stations record air temperature, barometric pressure, solar radiation, wind speed, wind direction, wind speed of peak gusts, and liquid precipitation. In-house assets include four stations.

Field instruments for in situ measurement of snow and ice properties provide thickness, salinity, and density data from cores. Physical temperature profiles of the pack are obtained from thermistor chains frozen into the ice and snow pack. Radiometric properties of sea ice at 33.6 GHz are obtained with NORDA's portable radiometer (Fig. 8). The instrument can be used either to make spot measurements or to make profiles of radiometric ice variability. The instrument can be mounted on a sled or a helicopter, depending on the length of traverse and trafficability of the surface. Measurements of transmission characteristics of ice and snow at 33.6 GHz are made using the radiometer in conjunction with a portable illuminator (Fig. 9).

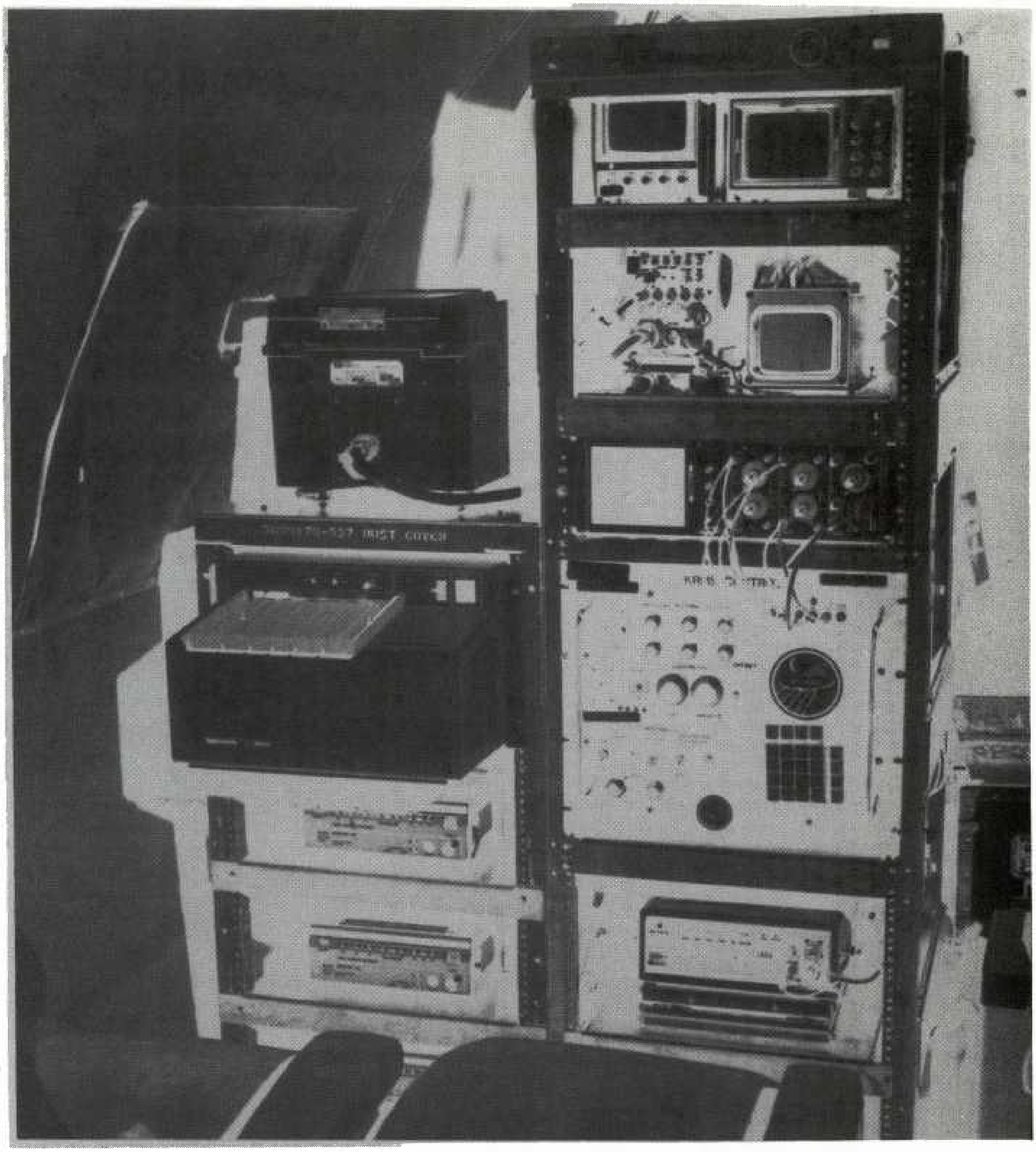

Figure 4. KRMS onboard display processor. The display processor, which controls operation of the KRMS instrument, is located in the aircraft cabin. Antenna scan rate and gain settings are monitored and controlled via the processor. Images are displayed in real time on the monitor and can be printed on the dry-process copier if hard copy images are required. The display processor weighs aproximately 400 pounds.

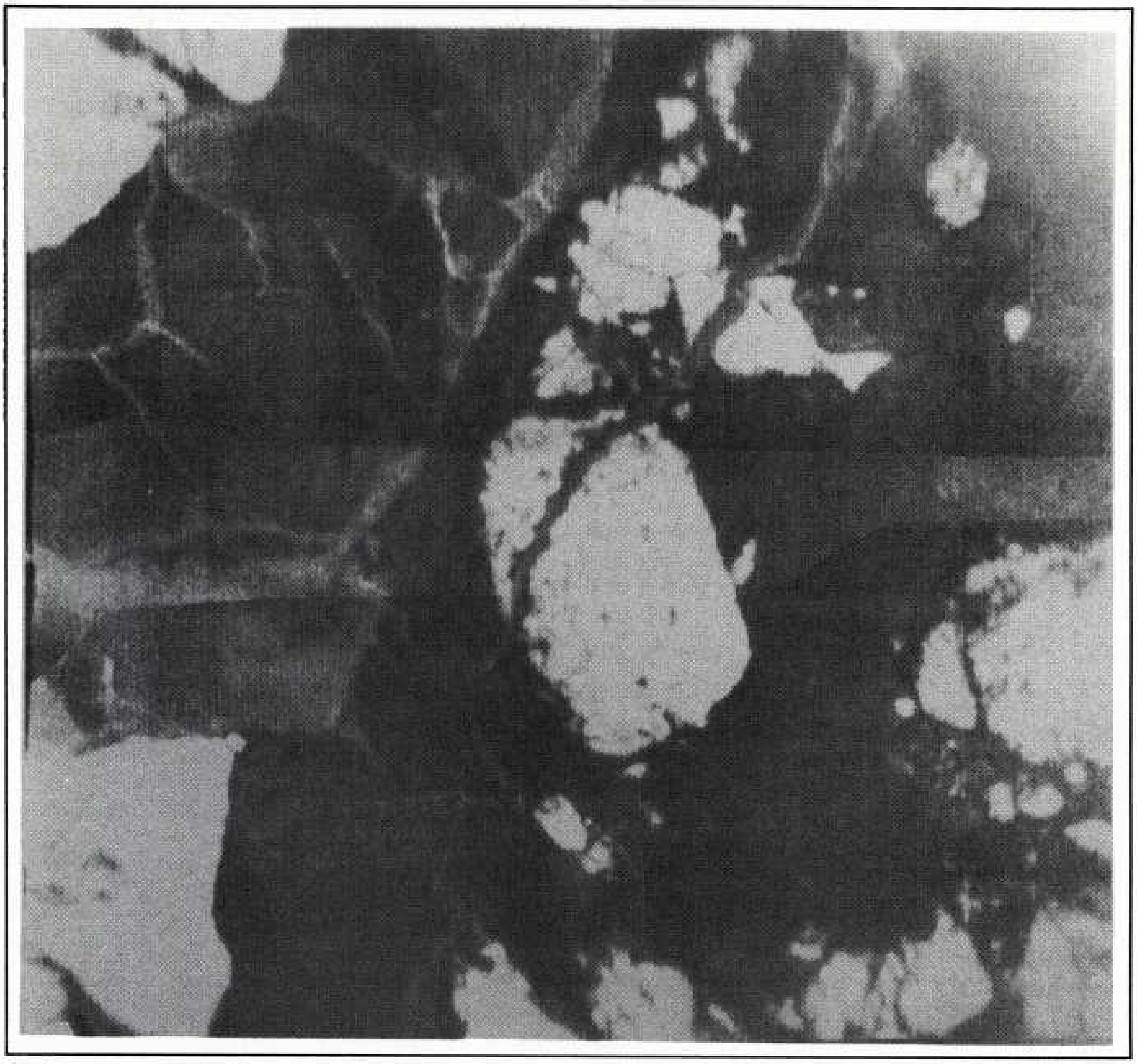

Figure 5. Mosaic of KRMS images shows a radiometrically cold multi-year ice floe (white) set in a matrix of radiometrically warm young ice and first-year ice (dark). Flight altitude is 3000 feet. The imaged scene is approximately 15,000 feet from side to side. Figure 6 is a mosaic of aerial photographs that shows the central portion of this scene.

C. Remote sensing assets

NORDA is equipped to receive, process, and display digital images transmitted by NOAA, DMSP, and Geostationary Operational Environmental Satellites (GOES). Images are received with the Satellite Data Receiving and Processing System (SDRPS). They can be navigated, calibrated, and enhanced using the Interactive Digital Image Processing System (IDSIPS). In addition, radar altimeter data of lower latitude polar regions is received in conjunction with the GEOSAT Ocean Applications Program (GOAP). Remote sensor data acquired through any of these NORDA programs can be relayed to field parties in near real-time via the ATS-3 communications satellite. Each of these remote sensing assets is described below.

1. Satellite Data Receiving and Processing System

NORDA's satellite receiving station is capable of acquiring digital data from the NOAA and DMSP polar

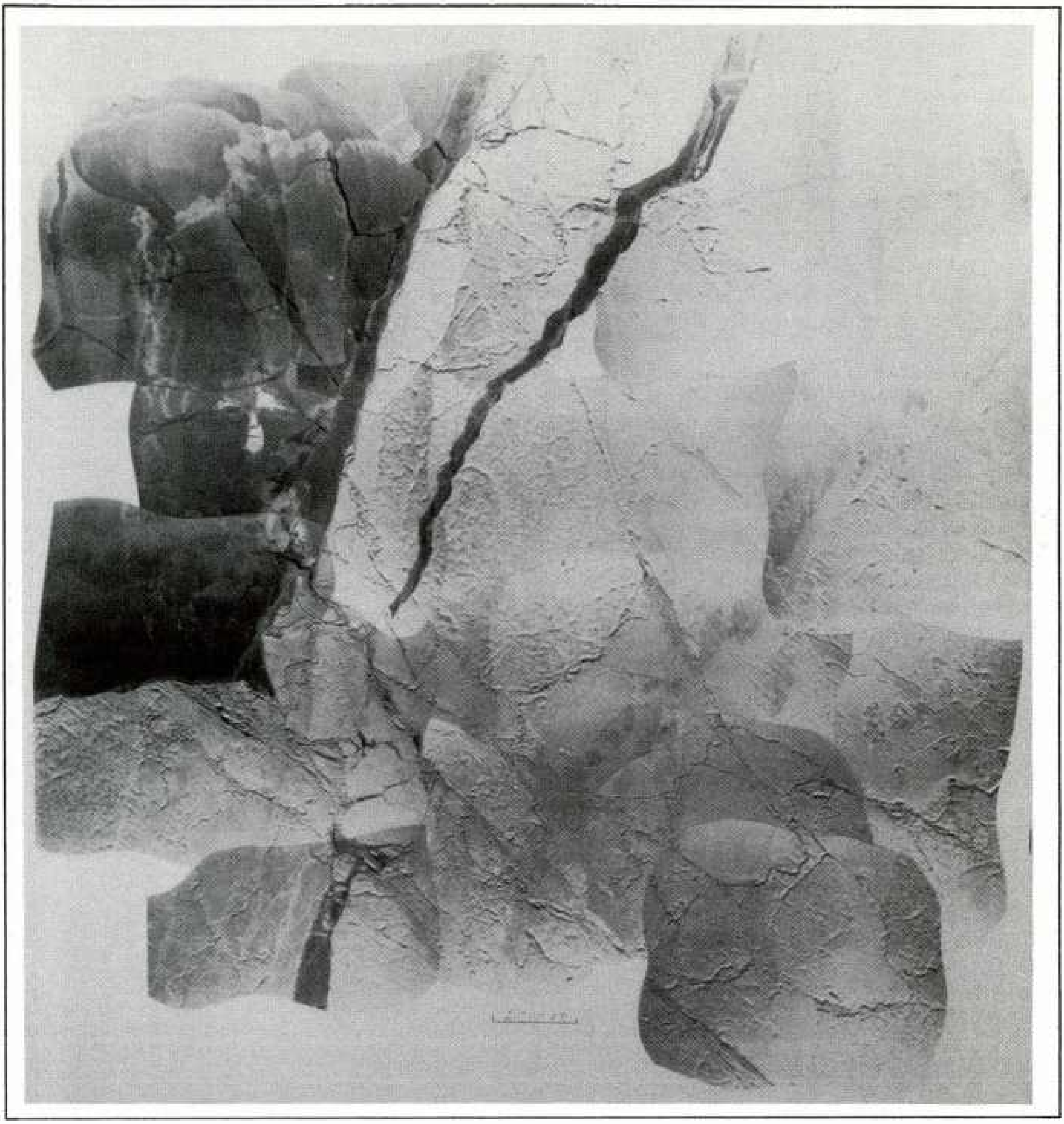

Figure 6. Mosaic of RC-10 aerial photographs that cover the central portion of the KRMS scene shown in Figure 5.

orbiters, as well as the Geostationary Operational Environmental Satellites-GOES (Hawkins et al., 1985). SDRPS consists of a Gould SEL (Systems Engineering Lab) 32/27 minicomputer that controls acquisition of visible and infrared data from the spacecrafts with four satellite antennas. User specified passes can be interactively selected ahead of time such that the system can be left unattended for days at a time. This selection capability allows us to receive data around the clock, 7 days a week.

Real-time line-of-sight DMSP data within the station viewing range (Fig. 10) are collected via a tracking antenna. This coverage does not include any Arctic imagery

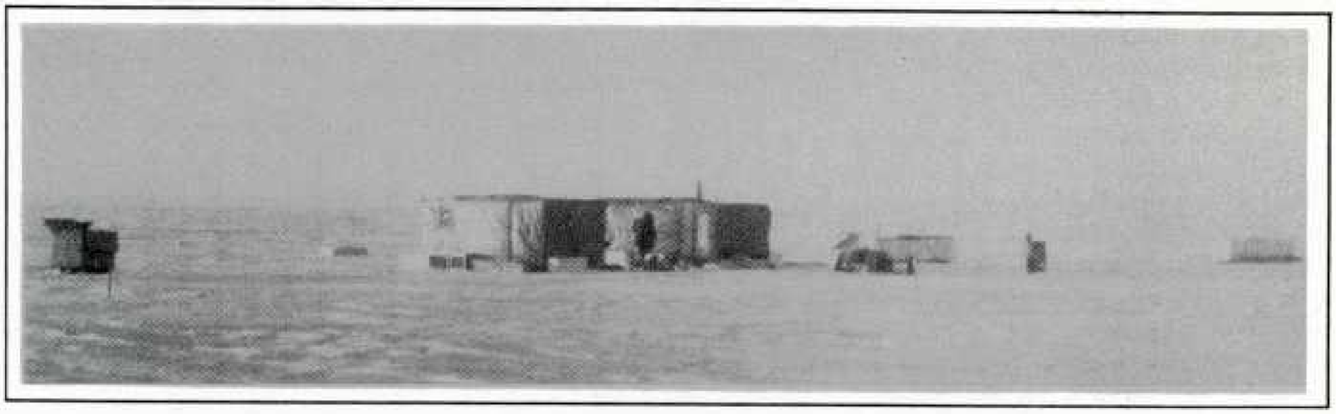

Figure 7. NORDA field camp located approximately 80 miles from Barrow, Alaska, in the Beaufort Sea. Each such camp can be equipped to support habitation for up to one month at a time without resupply.

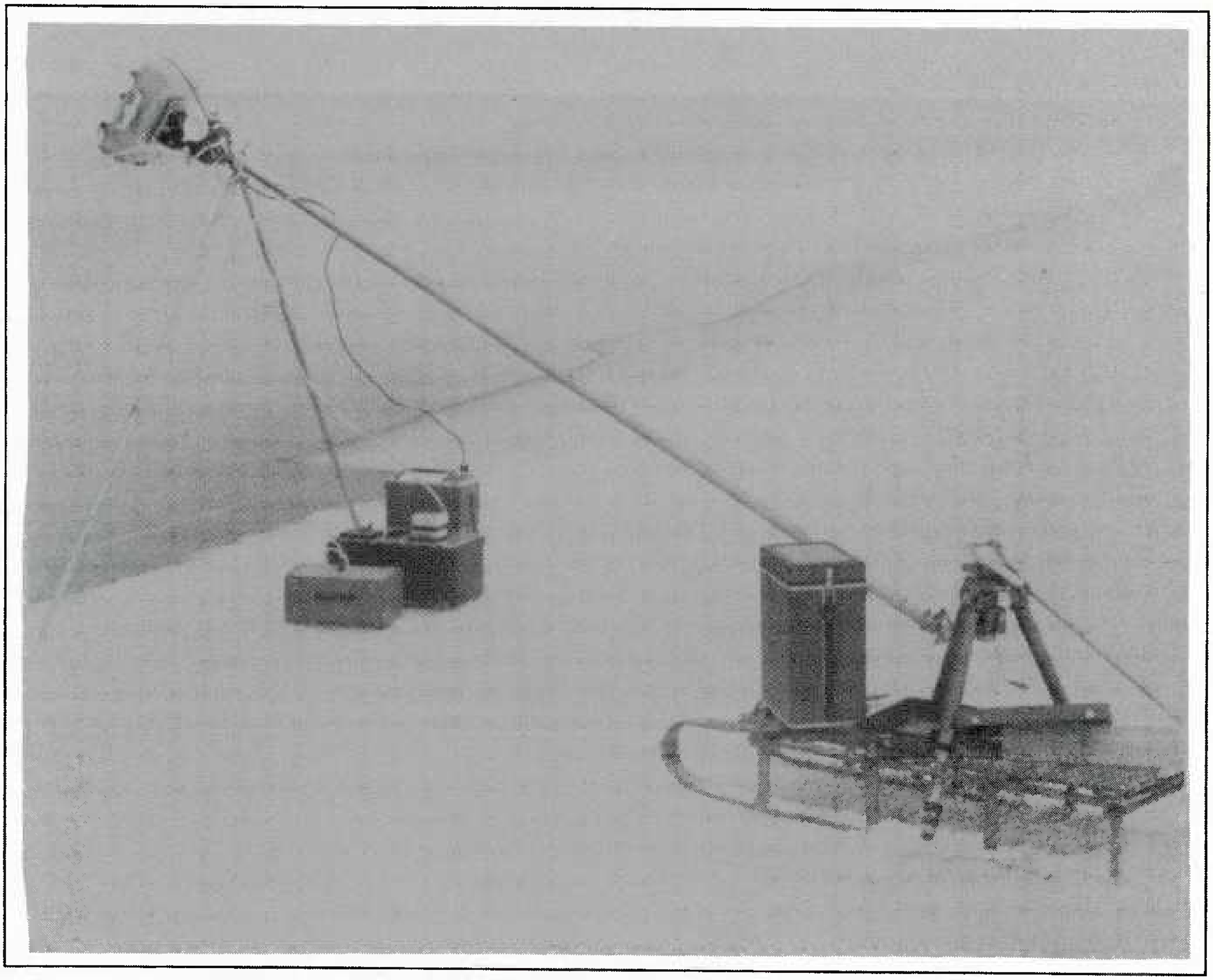

Figure 8. The portable 33.6 GHz radiometer provides ground-based measurements of radiometric properties of sea ice at the KRMS frequency. Profiles of ice characteristics are made by mounting the instrument on a sled or helicopter.

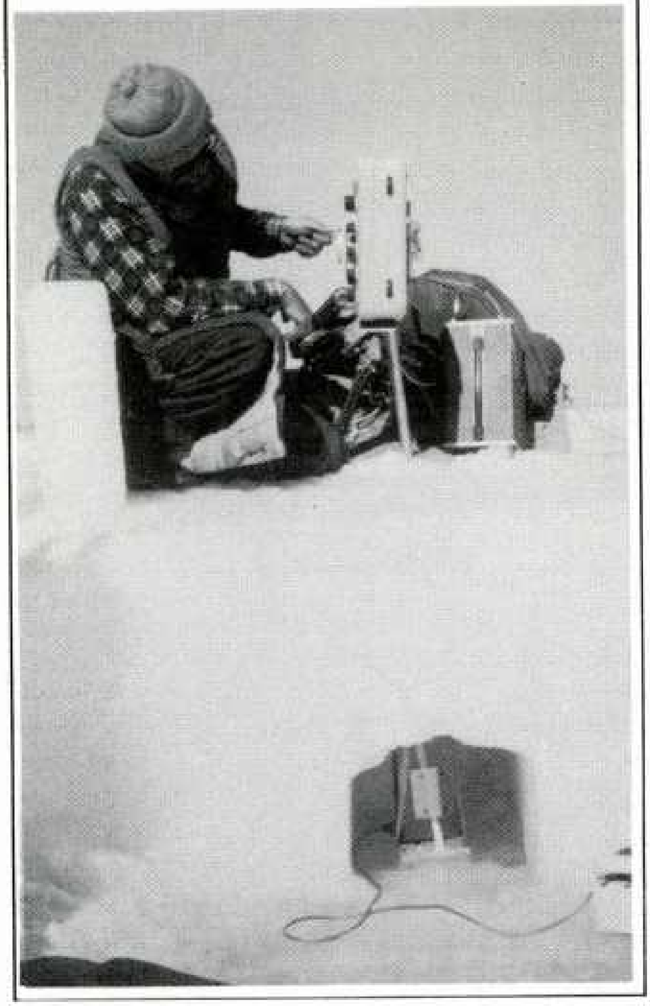

Figure 9. The 33.6 GHz illuminator (bottom) is used in conjunction with the protable radiometer to mesure transmission characteristics of snow and ice.

other than the Great Lakes for sea ice studies. Data acquired over the poles and stored onboard are now received at FNOC and at the Air Force Global Weather Center (AFGWC), Offutt Air Force Base, Omaha, Nebraska. We are looking into the software necessary to read stored DMSP digital data tapes. Polar DMSP imagery used for SSM/I validation could then be combined with NOAA data to form a comprehensive comparison database.

Two antennas are required to receive the real-time High Resolution Picture Transmission (HRPT 1.1 km) and stored NOAA/Tiros visible and infrared data from the Advanced Very High Resolution Radiometer (AVHRR). Figure 10 is, again, appropriate for outlining the circle for real-time data acquisition. Note that the sensor swath of 2900 km means that an area considerably larger than this approximate circle is actually sensed (i.e., the circle denotes where the subsatellite point must be for the satellite to be in view of the receiving antenna).

The NOAA satellite continuously transmits real-time HRPT data while orbiting the earth approximately 14 times each day. All five channels (one visible, one near-infrared, and three infrared channels) are included in this broadcast (Table 3). The NOAA platforms are also capable of recording 4 km averaged AVHRR data for the entire globe (Global Area Coverage—GAC data) and selected areas of full resolution (1.1 km) Local Area Coverage (LAC) data.

Reception of stored GAC and LAC data via a 10 m Domestic Communication Satellite (DOMSAT—geostationary) antenna can provide the high-resolution, near-real-time, multispectral visible and infrared data for the polar regions. Imagery is displayed on a CRT while being ingested for later processing. Gridded, earth-located data can then be displayed in a variety of enhancements within 5 minutes of reception. The digital data can then be archived on Computer Compatible Tapes (CCT) in the NESDIS Level 1b format for later examination.

The inclination of the NOAA polar orbiters, when combined with their large swath, offers excellent repeat visits for all of the polar regions. Orbital characteristics are such that consecutive passes 102 minutes apart provide considerable overlap. This is important when clouds may obscure the area of interest. A number of images over the same area may then reveal a series of cloud-free zones by virtue of the movement inherent in the cloud fields.

An example of NOAA channel 1 visible data is displayed in Figure 11. The digital data have been geometrically corrected for distortion that results from the earth's curvature and then remapped into a polar stereographic projection. Data are calibrated using onboard reference black bodies and represent a measurement of the reflectance, or albedo, of the medium below. Differentiation between the albedo values of clouds versus land is usually easy, but it is not as simple to distinguish sea ice and cloud reflectances. Threshold values to mask out the majority of the clouds can be derived, but identifying some cloud types from apparent sea ice is troublesome.

A global land/sea data base is incorporated to help separate which pixels are land, sea, ice, or clouds. Figure 11 has a black land mask inlayed and then outlined with the coastal boundaries. This process can be duplicated for any area of the world at high resolution and in a number of map projections, greatly aiding the ability to extract shore

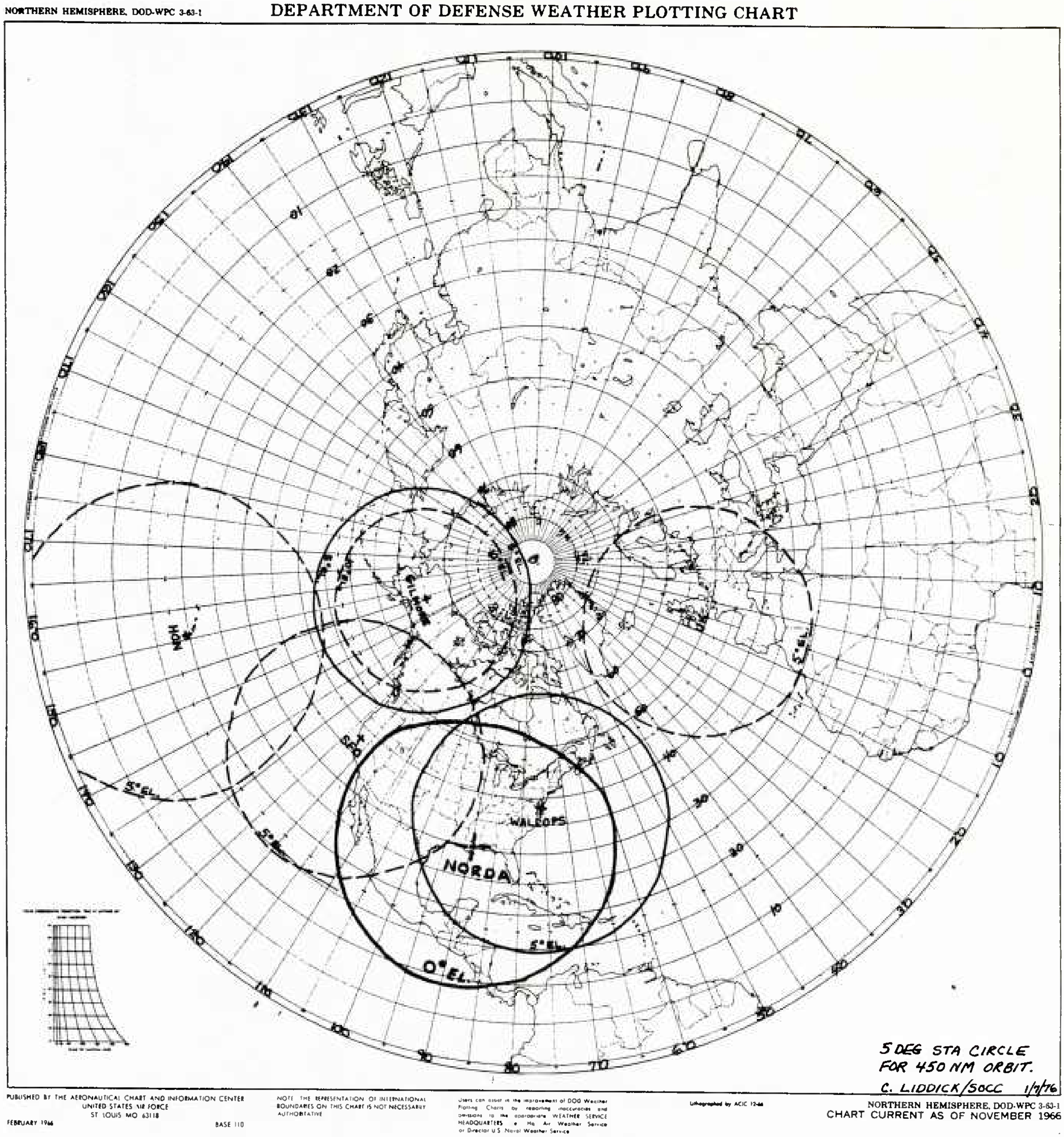

Figure 10. Polar stereographic map of the Northern Hemisphere indicating the areas of direct receive coverage for six different earth stations. NOAA and DMSP polar orbiter data can thus be acquired when a satellite passes within the circles.

Table 3. NORDA Satellite Data Receiving and Processing System (SDRPS).

Satellite	Sensor	Type Data	Spectral Bands	Spatial Resolution	Repetition Rate	Areal Coverage	Comments
NOAA-6 and NOAA-9	AVHRR (HRPT)	Digital Imagery	0.58 – 0.68 μm 0.725– 1.10 μm 3.55 – 3.93 μm 10.3 –11.3 μm 11.5 –12.5 μm*	1.1 km (Subpoint) 4 km (Edge)	12 hr each Satellite	≈2900 x 6200 km	Orbiting (806 + 863 km) Direct Readout and NOAA CDA Station Data Relayed via DOMSAT
	(LAC)	Digital Imagery	0.58 – 0.68 μm 0.725– 1.10 μm 3.55 – 3.93 μm 10.3 –11.3 μm 11.5 –12.5 μm*	1.1 km (Subpoint) 4 km (Edge)	12 hr each Satellite	≈2900 x 5000 km (Selected Global)	Recorded Data Relayed via DOMSAT
	(GAC)	Digital Imagery	0.58 – 0.68 μm 0.725– 1.10 μm 3.55 – 3.93 μm 10.3 –11.3 μm 11.5 –12.5 μm*	4 km (Subpoint) 16 km (Edge)	12 hr each Satellite	≈2900 km x Complete orbit (Selected Global)	Recorded Data Relayed via DOMSAT
	TOVS (HIRS/2) (SSU) (MSU)	Digital Data Digital Data Digital Data	Vis thru CO_2 in IR 15 μm 5.5 μm O_2 Band	17.4–58.5 km 147 km 124 km	12 hr each Sat 12 hr each Sat 12 hr each Sat	2240 km swath width 2240 km swath width 2240 km swath width (Global via DOMSAT)	Direct readout and data relayed via DOMSAT
	DCS	Platform Information	Environmental Measurement (e.g., temperature, pressure, altitude)	NA Location accuracy of plat- form is 3–5 km	6 hr	Global	ARGOS DCLS by CNES of France Direct Readout and Data Relayed via DOMSAT
DMSP F-6 and F-7	OLS	Digital Imagery	0.5 – 1.1 μm (Day) 0.45– 0.9 μm (night) 10.2 –12.8 μm	"Fine"–0.6 "Smooth"–2.8 km	12 hr each Satellite	3050 km swath	Orbiting (835 km) Direct Readout (RTD)
	SSM/I	Digital Imagery	19.35 GHz 22.235 GHz 37.0 GHz 85.5 GHz	69 x 41 km 60 x 36 km 35 x 22 km 16 x 10 km	12 hr each Satellite	≥1300 km swath width	Future Sensor (1986)
GOES EAST and WEST	VAS (Stretched VISSR)	Digital Imagery	0.55– 0.75 μm 10.5 –12.6 μm	0.8 km (Vis) 8.0 km (IR)	30 min	4000 x 4000 km (Vis) Full disc (IR)	GOES-E Failed 30 Jun 84 GOES-W at 108° W; was moved to 98°W 20 May 85

*NOAA-9 only.

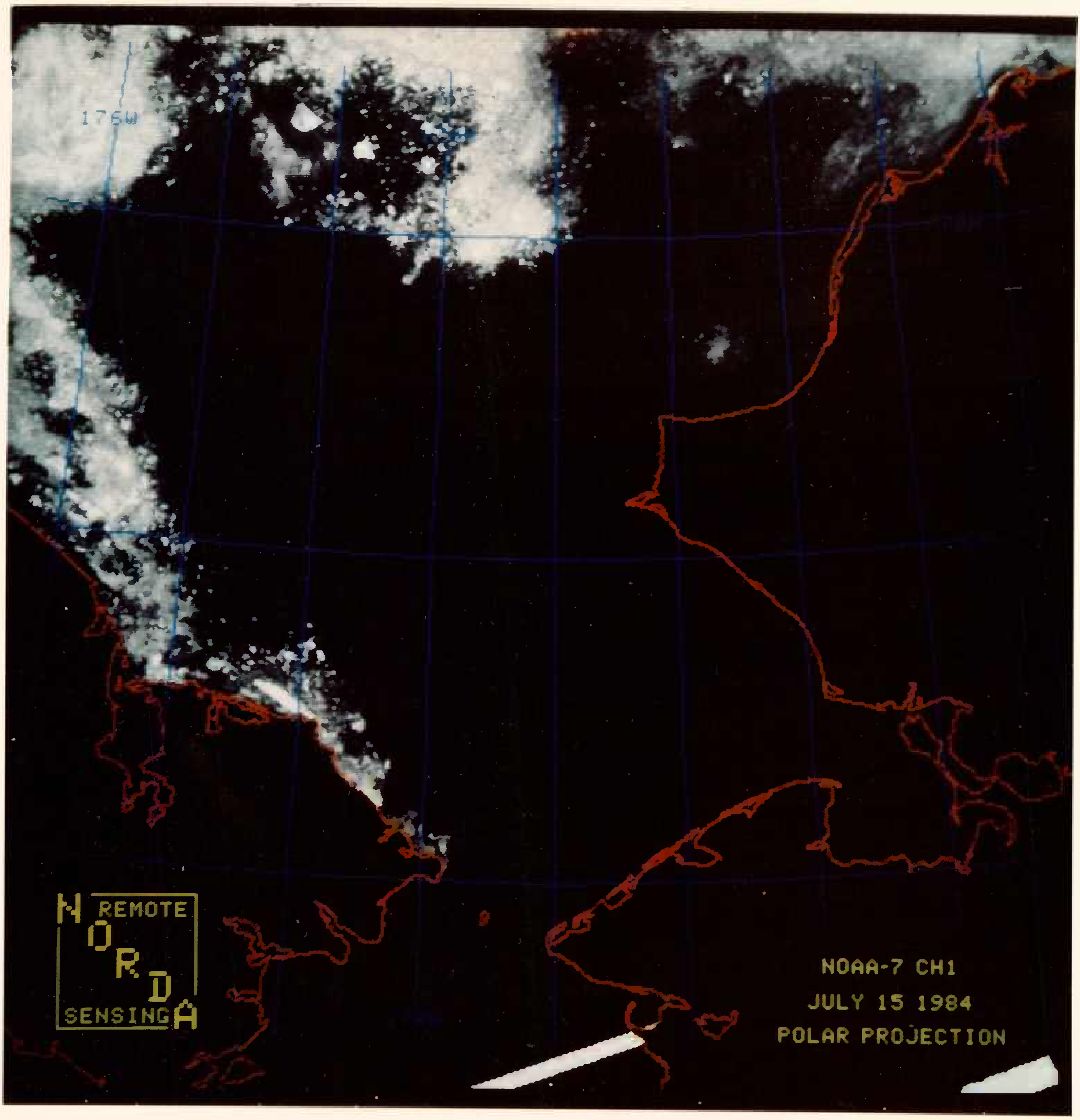

Figure 11. NOAA-7 visible (CH #1) image of the Chukchi Sea region on July 14, 1984. Image has been mapped to a polar stereographic projection with land mask, coastal boundaries and grid included. Enhancement has been done to bring out sea ice features.

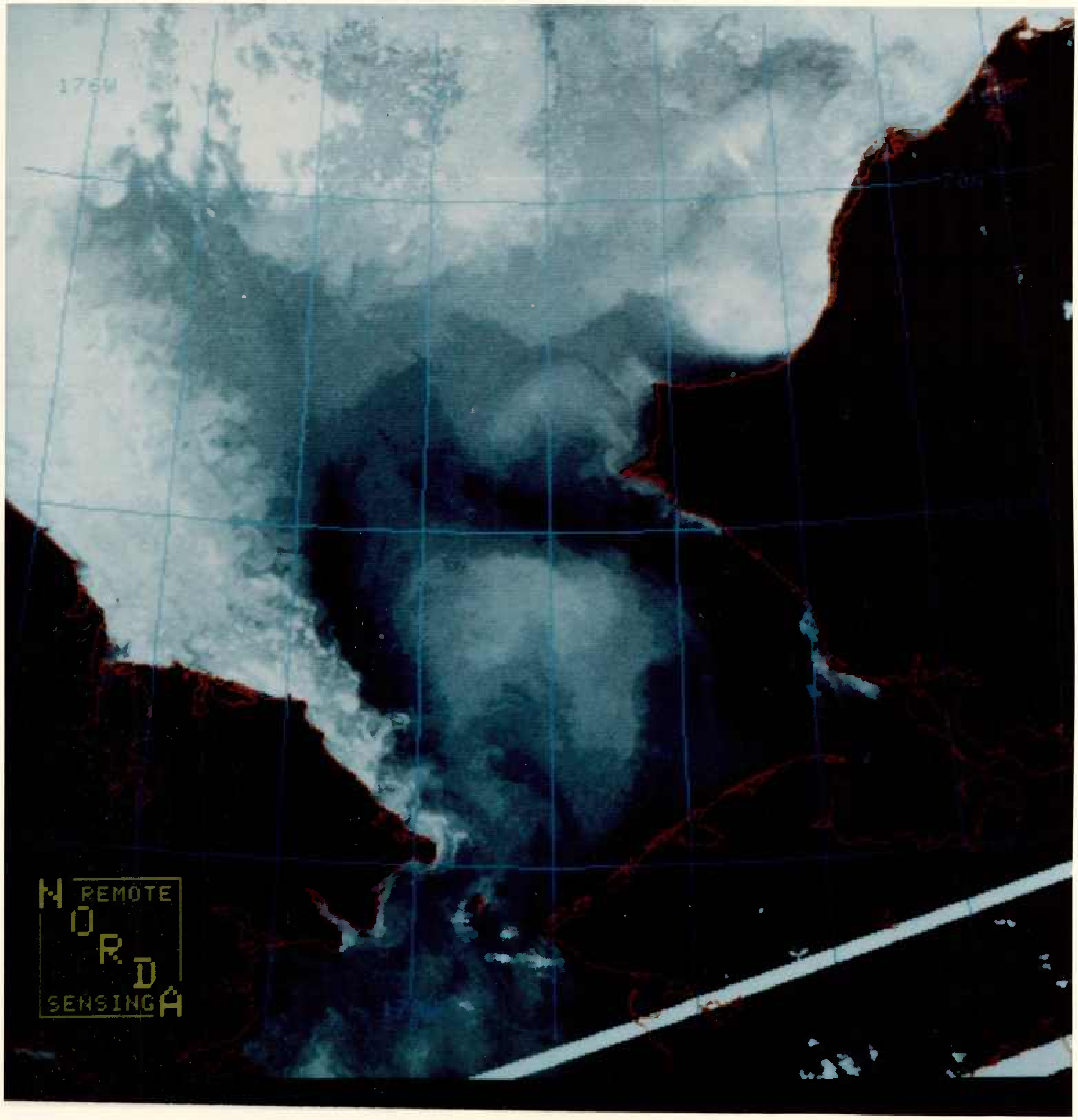

Figure 12. NOAA-7 infrared (CH #4) image of the Chukchi Sea region on July 14, 1984. Image has been mapped to a polar stereographic projection with land mask, coastal boundaries, and grid included. Water features (SST gradients) have been enhanced while sacrificing sea ice identification capabilities.

fast ice. User-specified gridding (i.e., include every 1, 2, 3°, etc.) can also be overlaid on the image, making feature matchup from one image to another very easy.

The 14 July 1984 image of the Chukchi-Bering Sea (Fig. 11) is contaminated by only a few clouds. The center is dominated by open water, and along the coast of the north-eastern portion of the U.S.S.R. is an assortment of sea ice types. The center segment is ice free until 70°N and reveals the presence of several ice types when enhanced interactively on the image-processing screen. This capability to change the contrast and brightness of the reflectance values in the image is a powerful tool when trying to grasp subtle changes in sea ice characteristics.

Figure 12 covers the same region as Figure 11, but reveals that infrared channel 4 can shed new light on any type of sea ice interpretation. The infrared data can be enhanced to bring out sea ice features or the sea surface temperature field along the ice edge or in the open water of the Chukchi Sea. This information provides an abundance of new information, not available in visible imagery, by depicting the surface flow of ice using identifiable features. An ice analyst who has knowledge of the gyre-like circulation illustrated in Figure 12 would be in a much better position to forecast ice movement along the north-eastern Soviet coast.

The beginnings of ice eddies and swirls of surface currents along the ice edge are apparent in Figure 12. When combined with calibrated infrared data, the sea surface temperature information can help determine whether certain regions are prime areas for ice growth or decay. For example, the advection of warm water into an area of thin ice would likely lead to some decay, depending on the amount, length of time, and prevailing atmospheric conditions.

The infrared data can play a major role as a validation tool, especially during those periods when insufficient lighting conditions render the aircraft and satellite visible imagery useless. Thus, IR information plays a crucial role when cloud-free images can be obtained. It should be noted that the images shown represent only a subsection of one AVHRR pass. Thus, the huge swath of this sensor can easily cover an entire day of aircraft underflights and provide continuity otherwise unobtainable. This point should not be underestimated. Knowledge of the big picture simplifies interpretation of smaller pieces of real estate.

2. Interactive Digital Image Processing System (IDSIPS)

IDSIPS consists of an HP-3000 minicomputer with three 200 megabyte (mb) removable pack disk drives and three International Imaging System (I^2S) displays. The interactive displays are utilized by activating any one of over 100 software routines (Stephenson, 1983). These modules provide the user with a wide range of image processing functions that include data input, geometric correction, earth location, calibration, image enhancement, etc. Any number of images can be multiplied, ratioed, added, subtracted, brightness and contrast stretched, filtered to bring out edges via a false three-dimensional perspective, false colored, or manipulated by a host of other functions.

The brightness and contrast stretching module is likely the single most powerful tool used. The digital counts in a visible, infrared, or microwave image can be manipulated to display just the range of values desired and then stretched over the 255 (8-bit) gray shades available on the monitor. Although the human eye can only see approximately 16 gray shades at any one time, the analyst can use this function to roam through the 255 gray shades as desired. This interactive capability immediately allows the operator to zero in on the features of prime interest and pull out information otherwise unobtainable.

The image-processing system will also allow the analyst to fade back and forth between any two images loaded in the refresh memories. Thus, by using the trackball, one can switch a display containing 100% of the visible image and 0% of the infrared, to a view that contains 100% of the infrared and 0% visible. All combinations in between are also obtainable in a matter of seconds. This capability has tremendous leverage in aiding the interpreter while selecting the correct ice type and concentration. Ambiguous entities in the visible imagery may then be identified by using enhanced, collocated infrared data.

IDSIPS also has the ability to digitize charts, maps, contoured data, etc., and enter them into the image processing system. Thus, if required, complementary data can be digitized and collocated with data already on the system by remapping the information into whatever standard map projection is used for a particular application. This is especially relevant if high-resolution maps of one kind or another are a vital part of the field program.

Two global databases are presently a part of the system. The World Data Base II is a high-resolution, land/sea definition database that includes everything from major geopolitical boundaries down to the location of salt pans and coral reefs. Thus, a map incorporating any or all 25 categories can be generated for any portion of the earth in a number of map projections and scale factors. This data was used to generate the land mask illustrated in Figures 11 and 12.

Also available is the Navy's Synthetic Bathymetric Profiling System (SYNBAPS), which contains depth

information of the ocean every 5 minutes of latitude and longitude. The digital nature of this database creates endless opportunities to contour bathymetry in the field program area. Any map projection can be used and interactive selection of the contour intervals provides increased flexibility. This feature can be useful in many shallow regions of the Arctic where knowledge of the bathymetry can help in interpreting ice features within an image.

3. Other remotely sensed polar data

NORDA is the Navy's lead research and development laboratory for the oceanographic exploitation of GEOSAT altimeter data in near real-time. The GEOSAT Ocean Applications Program (GOAP) (Lybanon, 1984) receives near real-time altimeter data from the Applied Physics Laboratory (APL) at Johns Hopkins University. Global data are collected and processed to derive sea surface wind speeds (magnitude only) and significant wave height (H 1/3) for the small, 2–5 km footprint of the active microwave sensor. This information is then passed to FNOC for input to fleet-generated products.

The GOAP effort has two main thrusts: detect mesoscale ocean fronts and eddies in the Gulf Stream region by means of their topographic and temperature signature and produce ice-edge data points to be sent to FNOC and then to the Naval Polar Oceanography Center (NPOC). The polar-orbiting GEOSAT will provide many sea ice crossings during its approximate 14 orbits per day as its high inclination arcs across the regions dominated by sea ice features.

4. Near real-time remote sensing field program support

NORDA's Remote Sensing Branch has provided near real-time assistance to many field program activities in need of high-resolution thermal imagery. A prime example of this capability was demonstrated during the recent Chemical Fronts Program cruise. NORDA's Biological/Chemical Oceanography Branch wanted to operate their new Towed Underwater Pumping System (TUPS) in an area possessing dramatic gradients of biological and chemical parameters, so they selected a portion of the Gulf Stream north wall as a testbed for the system. However, to understand the results clearly, they did not want any eddies, warm filaments, or streamers (i.e., meso/microscale features) to complicate data interpretation. The April–May cruise thus required near real-time thermal infrared imagery support to determine the location of a box suitable for the test experiment.

Real-time data from the NOAA AVHRR was acquired on SDRPS and then geometrically corrected and mapped into a Mercator projection. The full-resolution imagery was enhanced to bring out mesoscale ocean features, gridded, and then annotated before being sent by communications satellite (ATS-3) to the ship at sea. Scientists onboard were able to save and view imagery and then discuss a plan of action among themselves and with the onshore personnel.

This near real-time effort was essential in cutting down ship time required to find an ideal survey area. Otherwise, days of cruising and many expendable bathythermographs (XBTs) would have been needed to define the mesoscale oceanography of the study area. So far this capability has proven to be essential to the success of four field programs. programs.

IV. Application of assets

NORDA assets described above can be brought to bear on a variety of problems that affect Navy operations in polar regions. We use one example, validation of the untested SSM/I satellite remote sensor, to illustrate this point.

The SSM/I will return multi-band images of the polar regions. Algorithms described above will process data from selected bands and map ice concentration and ice-water boundaries throughout polar regions. The accuracy of these algorithms cannot be assessed fully until the satellite is launched for two reasons. First, antenna temperatures measured from orbit for known surfaces (water, first-year ice, old ice) may deviate from design criteria. As a consequence, overall instrument performance must be validated after launch so that values assigned to critical parameters within sea ice algorithms can be adjusted accordingly. Second, the algorithms themselves remain untested with SSM/I data. Ice concentration and ice edge retrievals thus must be validated with ground truth measurements to assess their accuracy.

In this light, an SSM/I validation experiment should be designed to meet two objectives. First, maps of ice concentrations and picks of ice-edge locations retrieved from SSM/I algorithms must be confirmed by ground, air, and satellite data. This objective arises from the need to verify that untested SSM/I ice algorithms perform properly and portray ice conditions accurately when actual SSM/I data are used as input. Second, radiometric values measured for Arctic surfaces by SSM/I sensors must be verified with coincident surface and airborne measurements. This task arises from the need to verify that SSM/I hardware is operating correctly and that values returned are within design limits established for sensor operation.

The algorithm validation phase will provide aerial photographs and microwave images, satellite visible and infrared data, and ground-based descriptions of sea ice conditions from which SSM/I algorithms can be fine tuned and their accuracy assessed. The sensor validation phase will provide both airborne and ground-based measurements of brightness temperature and emissivity from which operational characteristics of the SSM/I instrument can be defined.

A. Validate algorithm retrievals

The primary purpose of this phase of the validation effort would be to provide information with which to assess algorithm reliability so that appropriate adjustments can be made. As such, experiment objectives are twofold: document regional variation in ice conditions so that ice concentrations retrieved from SSM/I algorithms can be verified, and determine emissivities that are characteristic of a wide range of Arctic surfaces for input into SSM/I algorithms.

The SSM/I 1394 km swath, combined with the DMSP polar orbit, will allow the SSM/I to provide nearly complete daily coverage of the polar regions. The extent to which ice edge and ice concentration retrievals can be validated over this entire region is severely limited if ground truth and air truth data are used alone. Although the NORDA KRMS produces high-quality, high-resolution images, the area over which such data can be obtained is extremely small compared with the areal extent of the polar ice caps. Thus, the number of matchups between airborne images and SSM/I pixels collected for validation is only a fraction of the area that the SSM/I views.

The capability exists to narrow this gap by incorporating data from visible and infrared satellite sensors. Visible and infrared instruments onboard the operational NOAA and DMSP polar orbiters routinely gather digital data for swaths twice as large as the SSM/I. When not hampered by cloud cover, their high spatial resolution (0.5–4.0 km) provides accurate definition of the ice edge, ice concentration and, sometimes, ice age. This definition is optimized when the full thermal and spatial sensitivities of the sensors are preserved and displayed on an appropriate image processing system. NORDA has this required combination of satellite digital data and image-processing hardware and software.

Full-resolution (1.1 km) LAC data is continuously requested for many areas by the Naval Polar Oceanography Center (NPOC), Suitland, Maryland, to help determine sea ice conditions in both polar regions. Thus, any site chosen for SSM/I validation is probably already on the prioritized list for data acquisition within NOAA's satellite command station. If not, we do not foresee unmanageable problems in adding SSM/I validation areas to the existing list.

NORDA's airborne and ground-based assets, on the other hand, are well suited to support local aspects of the algorithm validation phase of the experiment. Aerial photographs and airborne passive microwave images can be acquired over regions of interest. In-house expertise and equipment permits remote field camps to be established from which in situ measurements of ice characteristics can be made. Regional and local pack characteristics thus can be documented using a combination of satellite, airborne, and surface sensors. Anomalous ice conditions that SSM/I algorithms erroneously describe can be identified and characterized in detail. Features of special interest that appear in SSM/I images can be investigated as required.

Satellite infrared (NOAA) and microwave (Nimbus SMMR, GEOSAT altimeter) data could be merged with aircraft KRMS images along SSM/I ground tracks. Coincident high-resolution aerial photographs and satellite visible data would supplement KRMS images when light and weather conditions permit remote sampling. Ice concentrations derived from these independent data sources would be compared directly with retrievals from SSM/I ice algorithms. Field parties would investigate areas of special interest on SSM/I images that aerial data fail to resolve.

Regions sampled would be determined in conjunction with other agencies participating in the validation effort (Atmospheric Environment Service (AES) Canada, NRL). Maps of the experiment area that show the ice edge and contours of ice concentration by age would be plotted on a standard map projection agreed to by all participating organizations. These data would be derived both from direct observation and from non-SSM/I sources and would be made without knowledge of output from SSM/I algorithms. The assistance of a Navy Polar Oceanography Center (NPOC) ice analyst would aid in interpreting these compiled data. Only after compilation of non-SSM/I data is complete would output from SSM/I algorithms be evaluated. Our objective in this design is to provide a blind test of SSM/I algorithm capabilities.

We expect that a typical field program would encompass a 10-day time window during which we would provide the validation team with a number of visible and infrared images. This data would enhance the overall program in real-time planning and, later on, in generating the surface truth maps. A minimum of six to eight images per day can be expected if two polar orbiters are operational. This large number is due to the overlap of consecutive orbits at this latitude.

Near-real-time visible and infrared imagery from the NOAA series of polar orbiters could be processed and then sent either to the airfield where the SSM/I verification planes are located or directly to remote ice camps. This would provide a large area view of the sea ice conditions such that selection of optimum flight tracks for the next day is feasible and would give planners a quick view of the accompanying weather conditions over the regions of interest.

Synoptic imagery of sea ice conditions would decrease plane time searching for suitable study domains and provide up-to-the-minute information on changing sea ice conditions. It would also single out cloud-free sectors and thus ensure that the SSM/I validation program will have corresponding confirmation via visible and infrared satellite sensors, which is vital if we are to take advantage of all available resources.

The data transmitted from NORDA would also be important for relay to the on-ice field camps. Regional pack characteristics provide indications of pack stability. Deteriorating pack conditions might be predicted in time to avoid potential hazards. This prediction is critical because safety is the highest priority in any field program effort. The imagery could be sent via ATS-3 or MARISAT communication satellites, depending on site location. A polar-orbiting communication satellite may be required if the site is located too far north for geostationary transmission. It is possible to acquire data via normal telephone lines as well, if satellite links are not feasible for one reason or another.

The equipment required for this support is presently available and can be included in the SSM/I validation effort. It has the potential of being a vital segment of the overall verification while doing so for a minimal cost, especially when one considers the high cost of Arctic operations.

The NORDA KRMS would be the primary aircraft instrument and would be flown along SSM/I ground tracks using polar orbiter imagery and NPOC ice analyses as a guide in selecting which region to cover. Hardcopy KRMS imagery can be dropped to ground parties for near real-time investigation. These ground parties would document local pack characteristics in detail.

B. Validate sensor measurements

The accuracy of SSM/I sea ice algorithms depends, in large part, on the validity of emissivities (or brightness temperatures) assumed for water, first-year ice, and old ice. Departures of assumed values from actual conditions create errors in concentration estimates. It is essential that emissivities that are characteristic of three sets of surface conditions be documented for 1) winter conditions during which the surface is frozen, 2) summer conditions during which the surface is wet, and 3) spring and fall conditions during which changes in ambient temperature cause ice surfaces to freeze and thaw diurnally.

Ground parties would measure emissivities with portable radiometers; the NORDA 33.6 GHz radiometer would be the primary instrument. The winter experiment could be based at St. Lawrence Island. Thin ice is abundant in the polynya that recurs annually south of the island. Thicker ice is abundant north of the island. The summer experiment could be based from a point in close proximity to the summer pack.

Validation of SSM/I sensor measurements also requires use of aircraft sensors. The objective of the airborne experiment is to determine the degree to which brightness temperatures measured by the SSM/I 37 GHz channel conform to expected values. KRMS would provide air truth brightness temperature measurements across SSM/I data image swaths.

Satellite ground tracks would be flown as close as possible to the time SSM/I images are acquired. KRMS imagery would be acquired from a high altitude along an extended track at least as wide as one SSM/I pixel. Swath width of the KRMS sensor at 25,000 ft is 17.85 km (11.2 miles), or approximately half the size of the SSM/I 37 GHz channel footprint (Table 1). A minimum of two passes are required to image each SSM/I pixel completely. In subsequent processing of KRMS images, all brightness temperatures measured within each SSM/I footprint would be averaged to determine the mean brightness temperature obtained from the air truth (KRMS) data. These mean values would be compared with SSM/I measurements to determine whether SSM/I brightness temperatures depart from expected values.

V. References

Cavalieri, D. J., P. Gloersen, and W. J. Campbell (1984). Determination of Sea Ice Parameters with the NIMBUS 7 SMMR. *Journal of Geophysical Research*, v. 89, n. D4, p. 5355–5369.

Dwyer, R. E. and R. H. Godin (1980). *Determining Sea-Ice Boundaries and Ice Roughness Using GEOS-3 Altimeter Data*. NASA Contractor Report 156862, 45 p.

Eppler, D. T., L. D. Farmer, A. W. Lohanick, and M. Hoover (1984). *Digital Processing of Passive K_a-band Microwave Images for Sea Ice Classification*. Naval Ocean Research and Development Activity, NSTL, Mississippi, NORDA Technical Report 51, May, 54 p.

Gloersen, P. and F. T. Barath (1977). A Scanning Multi-Channel Microwave Radiometer for Nimbus-G and SEASAT-A. *IEEE Journal of Oceanic Engineering*, v. O3–2, n. 2, p. 172–178.

Hawkins, J. D. and Remote Sensing Branch (1985). Remote Sensing at NORDA. Transactions of AGU, EOS, v. 66, n. 23, pp. 482–483.

Lybanon, M. (1984). *GEOSAT Ocean Applications Processing (GOAP) Initial Data Processing and Analysis System Test and Evaluation Plan*. Naval Ocean Research and Development Activity, NSTL, Mississippi, NORDA Technical Note 270, 29 p.

Stephenson, G. D. (1983). *A Description of the NORDA Satellite Remote Sensing Hardware/Software for Perspective Users*. Naval Ocean Research and Development Activity, NSTL, Mississippi, NORDA Technical Note 205, 96 p.

Svendsen, E., K. Kloster, B. Farrelly, O. M. Johannessen, J. A. Johannessen, W. J. Campbell, P. Gloersen, D. J. Cavalieri, and C. Matzler (1983). Norwegian Remote Sensing Experiment: Evaluation of the Nimbus 7 Scanning Multichannel Microwave Radiometer for Sea Ice Research. *Journal of Geophysical Research*, v. 88, n. C5, p. 2781–2791.

Swift, C. T., L. S. Fedor, and R. O. Ramseier (1985). An Algorithm to Measure Sea Ice Concentration with Microwave Radiometers. *Journal of Geophysical Research*, v. 90, n. C1, p. 1087–1099.